Algorithmic Vertical Handoff Decision and Merit Network Selection Across Heterogeneous Wireless Networks

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Abstract: - Next generation wireless networks must be able to coordinate services between heterogeneous networks through multi-mode mobile terminals. Such heterogeneity poses a challenge to seamless handover since each access network has different operations. In this paper, the policies of multiple metrics for handoff to permit connectivity across UMTS and WLAN/WiMAX are designed. Moreover, how to select an optimal target network is an important issue to balance against the network condition and user preference. The considered metrics for handoff initiation include the predicted received signal strength (RSS) of neighbor networks and dwell time. The RSS is predicted by back propagation neural network which is beneficial to perform handoff early. Dwell time value depends on the user speed and moving pattern. The policy for triggering a handoff is that the RSS conditions are consistently true during dwell time, so that unnecessary handoffs are avoidable. The predictive RSS and current RSS conditions have different policies for real time and non-real time services in different networks. Policies in the merit function are presented to select an optimal network. The weighting factors in the merit function are dynamic to neighbor networks. To evaluate the algorithm, RSS prediction, network selection performance and handoff decision performance are considered. The results indicate that the proposed vertical handoff decision algorithm and network selection outperforms the other two approaches in performing handoff earlier and reducing the number of vertical handoffs, connection dropping, Grade of Service (GoS) while increasing the average utilization per call of WLAN/WiMAX networks.

Key-Words: - Dwell time, Handoff decision policy, Heterogeneous wireless network, Network selection, Vertical handoff

1 Introduction

A significant challenge for fourth generation (4G) wireless networks is to coordinate different types of existing networks as depicted in Fig. 1. This cooperation provides users with a wide range of services across different media through a single mobile terminal. For example, characteristics of 802.11 Wireless Local Area Network (WLAN), 802.16 Worldwide Interoperability for Microwave Access (WiMAX), (faster, high-bandwidth, lower-cost, limited-distance access) and third generation (3G) cellular such as Universal Mobile Telecommunications Systems (UMTS), (slower, higher-cost, long-range always connected access) can be complementary. Each network characteristics are summarized in Table 1. This universal wireless access requires the design of intelligent vertical handoff decision algorithms to allow the device to receive services even as it moves between different network access points [1, 2, 3]. Currently, there are various standardization bodies include the 3rd Generation Partnership Project (3GPP), 3GGP2 and the IEEE 802.21 Media Independent Handover (MIH) Working Group. IEEE 802.21 provides the protocols to support cross layer interaction but it does not consider factors to efficiently make handoff initiation and find an optimal target network [4].

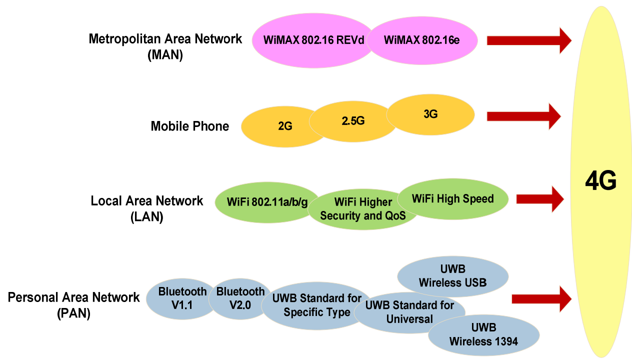


Figure 1. Evolution of wireless and mobile networks toward 4G ubiquitous access

In traditional handoffs [1, 3], received signal strength (RSS) is only a merit for handover decision which is not sufficient because the RSS of different networks cannot be compared directly, and moreover, it does not reflect network conditions adequately. To develop a vertical handoff decision algorithm, new metrics such as service type, monetary cost, network conditions, system performance, mobile terminal conditions and user preferences [2] should be criteria in conjunction with the RSS measurement. Multi-criteria in the policy-based approaches are not only for deciding when the handover occurs but also determine which network should be selected as a target network and whether handoff is worth [5].

In [6], predictive RSS (PRSS) is only a merit to decide whether to start a handoff while the comparison of quantitative decision values is used to select a target network. This considers the PRSS of the serving networks, not of the neighbor networks. It makes this algorithm is not practical because when a mobile node is in UMTS, it should know how strong the PRSS of the neighbor WLAN/WiMAX is to decide whether to handoff earlier. Cross layer based adaptive vertical handoff in [7] developed two handoff algorithms based on PRSS and current RSS. The first is for when a mobile node is in UMTS and second one is for when a mobile node stays in WLAN. Markov decision process determines an optimal target network. However, there is no dwell time to check the condition of the RSS comparison in order to avoid the ping-pong effect and the computation of Markov process depends on the number of WLAN networks. A counter in [8] serves as a dwell timer to ensure the conditions to be consistently true but it is fixed which may be too long if the mobile node's velocity is high. Moreover, the weight values in the merit function for finding the best possible target network do not adapt along the metric values. As a result, the counter and the weight values should be adaptive according to the real situation. Many vertical handoff decision algorithms are proposed in current literatures based on fuzzy logic due to the ability to take multiple parameters into account and give the best possible solution for handoff decision [9-15]. However, it needs to establish proper rules and requires large memory for databases to store rules. In [12, 13], two handoff scenarios: handoff from UMTS to WLAN and handoff from WLAN to UMTS are presented using Mamdani fuzzy logic to find out a handoff factor but it is difficult to define fuzzy sets for the network selection function. The algorithm presented in [14] uses only the mobile speed as the highest priority for the network selection. Sugeno Fuzzy logic [15] is for handoffs initiated by a mobile node while cost function with fixed weight values is for handoffs initiated by attachment points. However, it does not use the mobile speed as a metric to prevent a high velocity user from connecting to WLAN. Vertical handoff scheme should balance against user satisfaction and network conditions for different types of service applications.

In this paper, we present a policy-enabled vertical handoff algorithm satisfying user preference, network conditions and service application to select the most appropriate network for users. The policy is to minimize handoff delay for real time services and prolong staying time in WLAN for non-real time services. RSS of the serving network and the PRSS of the target networks integrated with a dwell timer are used to decide whether the handoff is triggered to reduce the number of unnecessary handovers [16]. Back propagation neural network [17] trains the RSS signals for prediction. The duration of dwell time depends on the movement of a mobile node. In the network selection procedure, the merit function [8] is adopted to find candidate networks satisfying the preference of a user. Dynamic weights are proposed so that the merit function is adaptive to different metrics of several networks. To evaluate the performance, we compare our proposed vertical handoff scheme to a fuzzy logic based approach and to the maximum PRSS based approach with hysteresis threshold [1, 16].

Table 1. Comparisons of Different Network Characteristics

Network Characteristic	IEEE 802.11g WiFi	IEEE 802.16e Mobile WiMAX	3G Cellular UMTS/WCDMA
Coverage	100-300 (m)	1.6-5 (km)	3-10 (km)
Bandwidth	54 Mbps	30 Mbps (10MHz BW)	1.8-14.4 Mbps (HSDPA+HSUPA)
Frequency	2.4 GHz	2-6 GHz	1920-1980 MHz (uplink) 2110-2170 MHz (downlink)
Cost of data services	Low	Medium	High
Security	Weak	Medium	High
No. of channels	13	Depending on country	12
No. of user/ channel	1	Many (100, …)	Many (order of magnitude: 25)

- HSDPA: High Speed Downlink Packet Access
- HSUPA: High Speed Uplink Packet Access

The rest of this paper is organized as follows. Section 2 presents the RSS prediction using back propagation neural network. In section 3, dwell time is defined. Merit function is explained in section 4 to find the best possible network for users. We propose a dynamic weight according to the changes of the metrics. Vertical handoff algorithm is proposed in section 5. We also give a brief description on the Mamdani fuzzy logic based vertical handoff algorithm for comparison in section 6. Section 7 illustrates the simulation results. The conclusion is finally given in section 8.

2 Receive Signal Strength Prediction by Back Propagation Neural Networks

Received Signal Strength (RSS) is used to help a mobile node know whether it moves closer to or away from the monitored network. Given its future values of each target network, the mobile node can determine which target network it is toward to. By comparing the strength of the predicted RSS of each neighbor network, it can assist to find the target network that the mobile node is moving in the overlap area. As shown in Fig. 2, a mobile node is moving from network 1 toward either network 2 or 3. The strength of predicted RSS can assist to find the target network that is moving in the overlap area. Knowing RSS of neighbor networks ahead of time and if the current RSS of the serving network is lower than the threshold, then the mobile node can performs handoff early. Thus, it results in a better connection quality and a low dropping probability as well while it moves in the overlap area. We use the back-propagation training algorithm for a two-layer network as in Fig. 3 to predict the future RSS. The input and output of the hidden layer are denoted as z_i and y_j, respectively while the output of the network is denoted as o_k for $i = 1,2,...,I$, $j = 1,2,...,J$ and $k = 1,2,...,K$. These input and output values can be arranged in a vector notation as $\mathbf{z} = [z_1\, z_2 \ldots z_I]^t$, $\mathbf{y} = [y_1\, y_2 \ldots y_J]^t$ and $\mathbf{o} = [o_1\, o_2 \ldots o_K]^t$. The weight v_{ji} connects the i^{th} input with the input to the j^{th} hidden node and the weight w_{kj} connects the output of the j^{th} neuron with the input to the k^{th} neuron. Given P training pairs of inputs and outputs $\{(\mathbf{z}_1, \mathbf{d}_1), (\mathbf{z}_2, \mathbf{d}_2), ..., (\mathbf{z}_P, \mathbf{d}_P)\}$ the weights are updated after each sample pair as follow [17]:

1. For $p = 1$, submit training pattern $\mathbf{z}_p$ and compute layer responses

$$y_j = f\left(\sum_{i=1}^{I} v_{ji} z_i\right) \tag{1}$$

$$o_k = f\left(\sum_{j=1}^{J} w_{kj} y_j\right) \tag{2}$$

where $f(net) \triangleq \dfrac{2}{1+\exp(-\lambda net)} - 1$ and $\lambda > 0$.

2. Calculate errors

$$\delta_{ok} = \frac{1}{2}(d_k - o_k)(1 - o_k^2) \tag{3}$$

$$\delta_{yj} = \frac{1}{2}(1 - y_j^2)\sum_{k=1}^{K} \delta_{ok} w_{kj}. \tag{4}$$

3. Adjust the output layer weights and hidden layer weights using the delta learning rule

$$w_{kj} \leftarrow w_{kj} + \eta \delta_{ok} y_j$$
$$v_{ji} \leftarrow v_{ji} + \eta \delta_{yj} z_i \quad ; \quad \eta > 0.$$

4. Increase $p = p + 1$ and if $p < P$ then perform step 1 until $p = P$.

The learning procedure stops when the cumulative final error in the entire training set, $E = \sum_{p=1}^{P} \frac{1}{2} \left\| \mathbf{d}_p - \mathbf{o}_p \right\|^2$, below the upper bound $E_{\max}$ is obtained otherwise initiate the new training cycle.

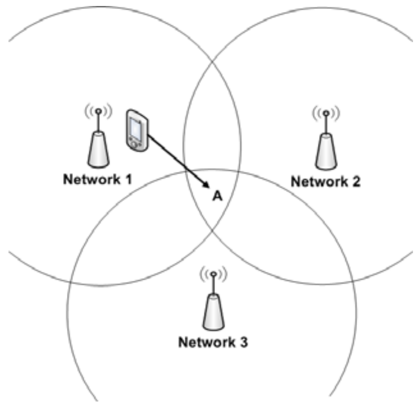


Figure 2. Mobile node is moving toward either network 2 or 3.

3 Dwell Time

The traditional handoff decision policy which is based on RSS, hysteresis and threshold can cause a serious ping-pong effect. To alleviate handoffs evoked too frequently, handoff would be performed if the conditions continue to be true until the timer

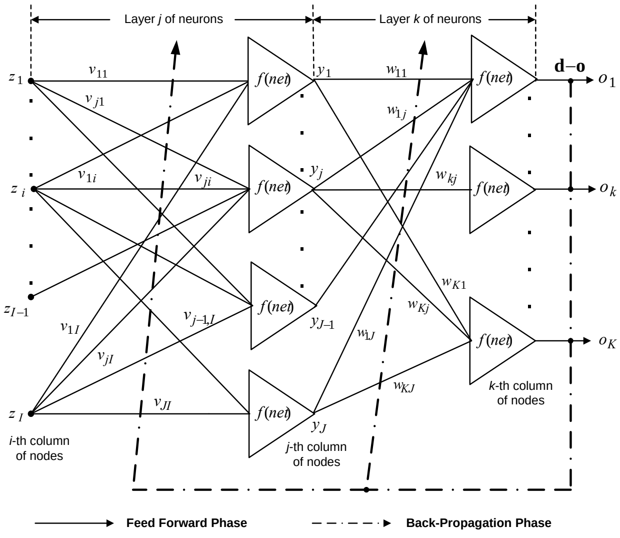


Figure 3. Two-neuron layers network.

expires [2, 3]. Dwell time is used as a timer which is adjusted according to the movement of the mobile node. The dwell time should be extended if the movement direction is irregular. It is defined as

$$t_d = \min\left[ubound(t_d), \left(1+avg\left(p_t\right)\right)\hat{t}_d\right] \qquad (5)$$

which the upper bound $ubound(t_d)$ depends on the mobile node's velocity. If the velocity is high, $ubound(t_d)$ should not be too long so that handoff is triggered before the mobile node already moves to the target network. On the other hand, $ubound(t_d)$ should be longer for a low velocity. $\hat{t}_d$ is the default value. p_t is the ping-pong flag at time t which is set to 1 if the direction changes between time t and $t-1$ more than 90°, otherwise $p_t = 0$ [18]. An average of the ping-pong flag from the past T samples until time t can be expressed as

$$avg\left(p_t\right) = \sum_{i=t-T}^{t} \alpha p_i \qquad (6)$$

where $0 < \alpha \le 1$ is an exponential smoothing factor. Note that we use the random waypoint mobility model [19] to determine the location and movement of the mobile nodes which enables us to calculate the mobile directions.

4 Merit Function

Merit function is a measurement of the goodness of a network from the user's point of view regarding to the running services. The merit function of network n is given by [8]

$$F_n = E_n \sum_i w_i \ln\left(q'_{n,i}\right) \qquad (7)$$

where $q_{n,i}$ is the i^{th} QoS factor in network n. If the increase of the factor value contributes the merit value to the network n, $q'_{n,i} = q_{n,i}$, otherwise $q'_{n,i} = 1/q_{n,i}$. The weighting factor, w_i, represents the importance of each metric to the user or to the network. E_n is the elimination factor of network n. The value of E_n is represented by zero or one to reflect whether network n is suitable for the mobile node's request. The policies of selecting a network are as follows. $E_n = 0$ if the data rate supported by network n is lower than that required by the current service, otherwise $E_n = 1$. Suppose that the current service is real-time video, if UMTS cannot provide such a service; it should be deleted from the candidates. In addition, $E_n = 0$ if the user's velocity is more than that provided by network n, otherwise $E_n = 1$. For example, if the mobile node is moving very fast, it is useless to handoff to WLAN. The QoS factors include available bandwidth (B), monetary cost (C) and user preference (P). Then, the merit function of network n can be calculated as

$$F_n = E_n\left(w_B \cdot \ln B_n + w_C \cdot \ln\frac{1}{C_n} + w_P \cdot \ln P_n\right). \qquad (8)$$

A method to calculate the weights w_B, w_C and w_P adaptively is presented in the next subsection.

4.1 Dynamic Weights

The vertical handoff decision algorithm is a multiple attribute decision making process. The weights of each metric in a candidate network should be adjusted to reflect the metric priority relative to the other attributes in different candidate networks. To scale the values in different units, normalization is needed. The normalized functions of B_n, C_n and P_n are given by [15]

$$\mathrm{N}\left(B_n\right) = \frac{B_n - B_{\min}}{B_{\max} - B_{\min}}; \mathrm{N}\left(C_n\right) = \frac{C_n - C_{\min}}{C_{\max} - C_{\min}}; \mathrm{N}\left(P_n\right) = \frac{P_n}{10} \qquad (9)$$

where $B_{\max}$ and $B_{\min}$ are the maximum and minimum bandwidth which network n can offer. $C_{\max}$ and $C_{\min}$ are the maximum and minimum charges regarded from expensive to cheap. The user preference range is from 0 to 10. User preference is high, when a user prefers to select WLAN and it is low if a user prefers to stay UMTS. For N

networks, we define mean and standard deviation as follows [6]:

$$m_B = \frac{1}{N}\sum_{n=1}^{N} \mathrm{N}(B_n);\ m_C = \frac{1}{N}\sum_{n=1}^{N} \mathrm{N}(C_n);\ m_P = \frac{1}{N}\sum_{n=1}^{N} \mathrm{N}(P_n) \quad (10)$$

$$\sigma_B = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N}\left(\mathrm{N}(B_n)-m_B\right)^2};\ \sigma_C = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N}\left(\mathrm{N}(C_n)-m_C\right)^2};$$
$$\sigma_P = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N}\left(\mathrm{N}(P_n)-m_P\right)^2}. \quad (11)$$

In fact, the smaller mean is, the more important the factor is. The larger standard deviation is, the larger the weight should be assigned. It leads to adjust the weights dynamically by

$$\phi_B = \exp(-m_B + \sigma_B);\ \phi_C = \exp(-m_C + \sigma_C);$$
$$\phi_P = \exp(-m_P + \sigma_P). \quad (12)$$

Letting $\Phi = \phi_B + \phi_C + \phi_P$, the dynamic weights is defined as

$$w_B = \frac{\phi_B}{\Phi};\ w_C = \frac{\phi_C}{\Phi};\ w_P = \frac{\phi_P}{\Phi}. \quad (13)$$

5 Vertical Handoff Algorithms and Target Network Selection

Our proposed vertical handoff algorithm between UMTS and WLAN/WiMAX networks is shown in Fig. 4. The handoff policy is different depending the user services and network characteristics. For non-real time services (e.g. ftp) the amount of data transmission is more important than the delay. Therefore, the handoff policy for non-real time service is to attempt to connect WLAN/WiMAX as long as possible due to higher data rate provided. For real time applications (e.g. Voice over IP), handoff should be performed as rapid as possible in order to minimize the delay.

5.1 Handoff from UMTS to WLAN/WiMAX

Figure 4 (a) shows the downward vertical handoff algorithm which a mobile node using services in UMTS network could always enter to WLAN/WiMAX to obtain a higher QoS at a less cost. Each step has the following policies [2, 20].

1. The preferred handoff point for non-real time services is the first time the PRSS from WLAN/WiMAX $(PRSS_W)$ reaches an acceptable level. The condition of this policy is given by

$$RSS_{th\_d,W} \le PRSS_W \le RSS_{\min\_d,W} \quad (14)$$

where $RSS_{th\_d,W}$ is the RSS threshold and $RSS_{\min\_d,W}$ is the minimum RSS in WLAN/WiMAX for the downward vertical handoff.

2. The preferred handoff point for real time services is the last time the $PRSS_W$ reaches the acceptable level. That is

$$RSS_{\min\_d,W} \le PRSS_W \le RSS_{\max\_d,W} \quad (15)$$

where $RSS_{\max\_d,W}$ is the maximum RSS in WLAN/WiMAX for the downward vertical handoff. Note that $RSS_{th\_d,W} < RSS_{\min\_d,W} < RSS_{\max\_d,W}$.

3. If one of above two policies is true, we continue to check the condition, $PRSS_W \ge RSS_{th\_d,W}$. If the condition fails before the dwell timer expires, the handoff process is reset, otherwise go on.

4. In this step, the RSS of a mobile received from WLAN/WiMAX is being increase. Then, we check if the mobile node is moving out of the coverage UMTS network by

$$RSS_{UMTS} \le RSS_{th,UMTS} \quad (16)$$

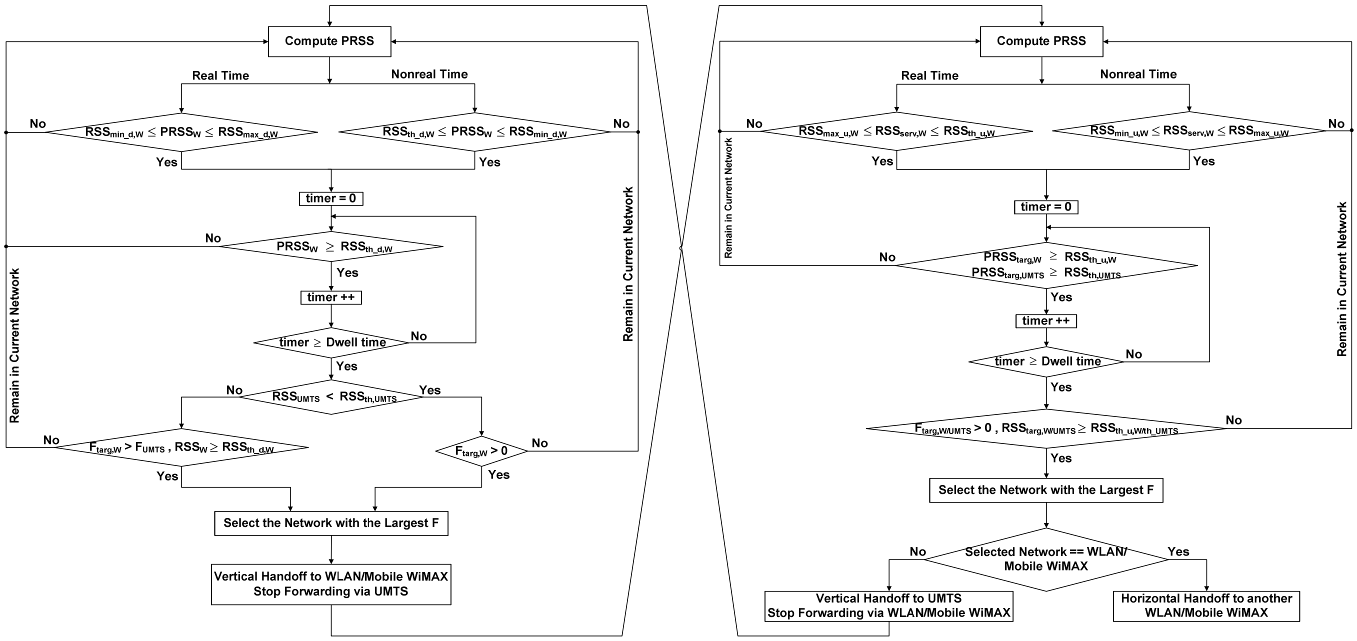
where RSS_{UMTS} is the RSS that the mobile node receives from the UMTS base station, and $RSS_{th,UMTS}$ is the RSS threshold in the UMTS network.

If the condition is true, it means the mobile user is moving out of the coverage UMTS network. Any available WLAN/WiMAX networks satisfying $F_n > 0$ are candidates. We choose a target network that has the merit function more than zero in order to keep service quality and prevent the call from being dropped. In the case that this condition fails, it means the mobile user is not moving out but the RSS in WLAN/WiMAX (RSS_W) is larger than the threshold. The networks having the merit functions higher than that of UMTS $(F_{\mathrm{targ},W} > F_{UMTS})$ are candidates. This ensures the mobile node has a better performance.

5. The network with the largest merit value among the candidates is selected as the target network.

5.2 Handoff from WLAN/WiMAX to UMTS or to another WLAN/WiMAX

Algorithm for the upward and intrasystem vertical handoff is shown in Fig. 4 (b). When a mobile node stays in WLAN/WiMAX, the policies to decide whether a handoff is performed are as follows:



(a) Downward vertical handoff procedure (b) Upward/Intrasystem vertical handoff procedure

Figure 4. Vertical handoff decision algorithm and network selection

1. The preferred handoff point for non-real time services is the last time the RSS in the serving WLAN/WiMAX network $\left(RSS_{\text{serv},W}\right)$ falls below the acceptable level. That is the $RSS_{\text{serv},W}$ is being in the interval of

$$RSS_{\min\_u,W} \le RSS_{\text{serv},W} \le RSS_{\max\_u,W} \tag{17}$$

where $RSS_{\min\_u,W}$ and $RSS_{\max\_u,W}$ are the minimum and maximum RSS in WLAN/WiMAX network for the upward and intrasystem vertical handoffs, respectively.

2. The preferred handoff point for real time service is the first time the $RSS_{\text{serv},W}$ degrades to the threshold RSS values $\left(RSS_{th\_u,W}\right)$ as

$$RSS_{\max\_u,W} \le RSS_{\text{serv},W} \le RSS_{th\_u,W} \tag{18}$$

where $RSS_{\min\_u,W} < RSS_{\max\_u,W} < RSS_{th\_u,W}$.

3. In this step, $RSS_{\text{serv},W}$ becomes weak. Find out candidate networks that have strong PRSS last for the dwell time duration by

$$PRSS_{\text{targ},W} \ge RSS_{th\_u,W} \text{ and } PRSS_{\text{targ},UMTS} \ge RSS_{th,UMTS}. \tag{19}$$

4. The handoff should now be triggered. The candidate networks are the networks having strong RSS and the merit function more than zero $\left(F_{\text{targ},W/UMTS} > 0;\, RSS_{\text{targ},W/UMTS} \ge RSS_{th\_u,W/th\_UMTS}\right)$. The target network is chosen from the candidates that have the largest merit. If the merit values are equal, the network selection is prioritized as WLAN > WiMAX > UMTS.

6 Fuzzy Logic based Vertical Handoff Algorithm

To compare our proposed vertical handoff algorithm, a Mamdani fuzzy logic inference system [21] is explained. It is composed of a fuzzifier, a fuzzy inference engine and a defuzzifier as shown in Fig. 5. A fuzzification changes input parameters from the crisp numbers into the fuzzy sets by appropriate membership functions. Then, fuzzy inference aggregates the analyzed fuzzy sets based on the pre-defined fuzzy rules. Finally, a crisp output for the aggregated value is given through the defuzzification process.

The input metrics include Received Signal Strength (*RSS*), bandwidth (*B*), monetary cost (*C*), user preference (*P*) and velocity (*V*). Each of the input parameters is transformed to one of three fuzzy sets (Low, Medium, High) by the membership functions. The membership functions of each input are shown in Figs. 6 (a)-(e). Note that the input parameters belongs to the target WLAN/WiMAX network for the UMTS-to-WLAN/WiMAX handoff while only the RSS metric belongs to the serving WLAN/WiMAX network for the WLAN/WiMAX-to-UMTS handoff. The fuzzy inference system uses the max-min Mamdani implication method where some of IF-THEN rules are defined as follows:

- IF *RSS* is Low, and *B* is Low, and *C* is High, and *P* is Low, and *V* is High, THEN Handoff Factor is Low.
- IF *RSS* is Medium, and *B* is Low, and *C* is Medium, and *P* is High, and *V* is Medium, THEN Handoff Factor is Medium.
- IF *RSS* is High, and *B* is High, and *C* is Low, and *P* is High, and *V* is Low, THEN Handoff Factor is High.

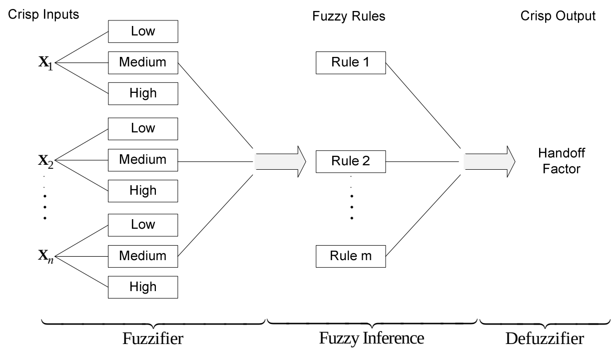
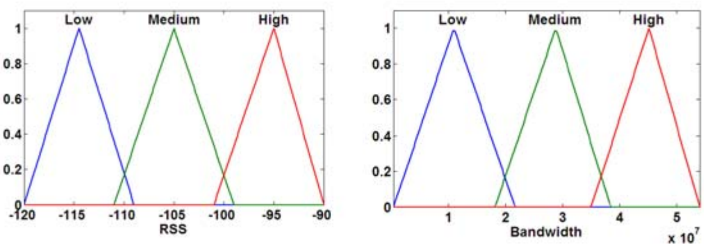


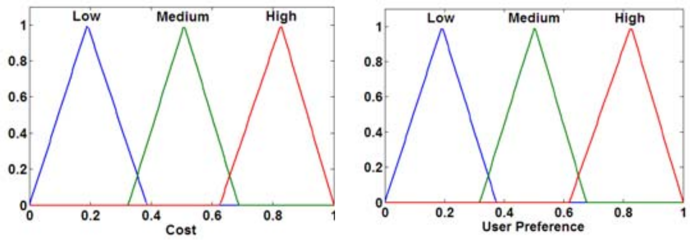
Figure 5. Fuzzy logic system

The range of handoff factor is from 0 to 10 with the fuzzy set value as shown in Fig. 6 (f). Using a weighted average defuzzification [21], the crisp handoff factor is obtained which is used to select the most appropriate network. The handoff decision is divided into the following conditions [15].

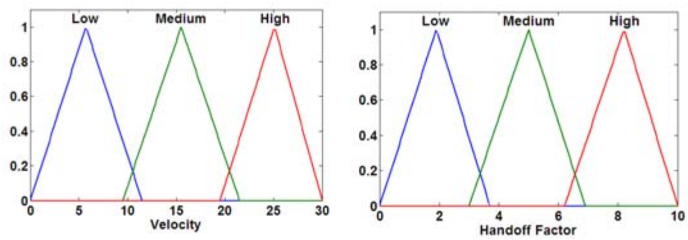
- If the crisp output is less than 4, then UMTS network is selected. If the current serving network is WLAN/WiMAX, then the mobile node makes a handoff; otherwise no handoff.
- If the crisp output is more than 7, then WLAN/WiMAX network is selected. If the current serving network is UMTS, then the mobile node makes a handoff; otherwise no handoff.
- If the crisp output is between 4 and 7, then the mobile node stays in the current serving network.



(a) (b)



(c) (d)



(e) (f)

Figure 6. Membership functions of input metrics (a) RSS, (b) bandwidth, (c) monetary cost, (d) user preference, (e) velocity and (f) membership function of handoff factor output

7 Simulation Results

This section evaluates the performance of the proposed vertical handoff decision mechanism denoted by PRSS+Merit. The channel propagation model of the RSS received by a mobile node is different in different types of networks. The RSS model of UMTS is given as following:

$$RSS(d) = P_t - PL(d) \qquad (20)$$

where P_t is the transmit power, and $PL(d)$ is the path loss at distance d (meters) between a mobile node and a base station. The path loss is defined as [9]

$$PL(d)_{\text{dB}} = S + 10n\log(d) + \chi_\sigma \qquad (21)$$

where S denotes the path loss constant, n denotes the path loss exponent and χ_σ represents the shadow effects which is a zero-mean Gaussian distributed random variable with standard deviation σ (dB).

In WiMAX, the path loss at distance d is formulated as [22]

$$PL(d)_{\text{dB}} = 20\log\left(\frac{4\pi d_0}{\lambda}\right) + 10n\log\left(\frac{d}{d_0}\right) + \chi_\sigma \qquad (22)$$

where the first term represents the free space path loss at the reference distance d_0, λ is the wavelength. We set n equal to 4 and a carrier frequency equal to 3.5 GHz.

In WLAN, the RSS received by a mobile node is computed based on the propagation model as [7]

$$RSS(d)_{\mathrm{dBm}} = 10\log\left(\frac{100}{(39.37d)^{\gamma}}\right) \quad (23)$$

where γ denotes the environmental factors of transmissions which is set to 2.8. The RSS is sampled every 1 sec. The network and simulation parameters are summarized in Table 2 and 3, respectively. The RSS prediction, the network selection performance and the handoff decision performance are evaluated.

7.1 RSS Prediction

In this section the RSS is predicted by the back-propagation neural network that is explained in section 2. Four input nodes $(I = 1)$, four hidden nodes $(J = 1)$ and one output $(K = 1)$ are used which does not consume much time for computation. We consider two cases as

1. Mobile node is assumed moving out the UMTS as shown in Fig. 7. The RSS that the mobile node receives from the UMTS base station is used to predict. We assigned $P_t = 1$w, $S = 19$dBm, $n = 3.5$ and $\sigma = 6$dB in Eqs. (20) and (21) for simulation Location information is detected every 1 sec. The mobile node has a constant velocity 5 m/s. The received signal strength from UMTS base station that is predicted by back-propagation neural network is accurate to the actual values as demonstrated in Fig. 8.

2. Mobile node is assumed going toward the WLAN as shown in Fig. 9. The RSS that the mobile node receives from the WLAN access point is predicted. The actual RSS can be calculated by using Eq. (23). We observe that the predictive RSS is closed to the actual RSS as shown in Fig. 10.

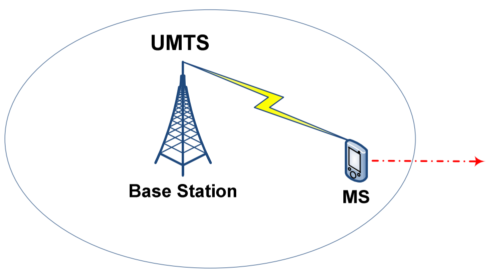


Figure 7. Mobile node is moving out UMTS

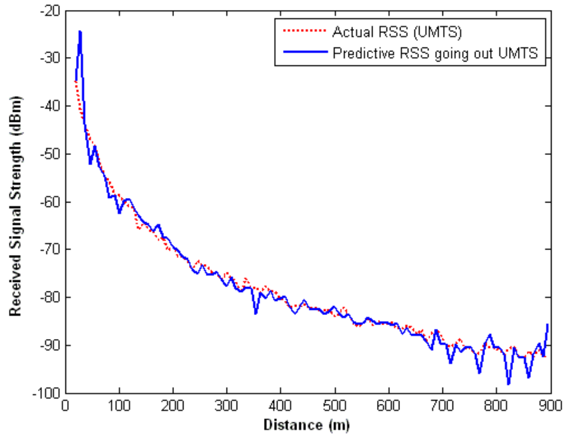


Figure 8. Predictive RSS received from UMTS base station when a mobile node is moving out UMTS

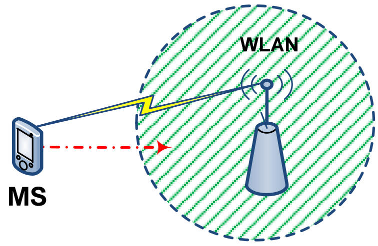


Figure 9. Mobile node is moving toward WLAN

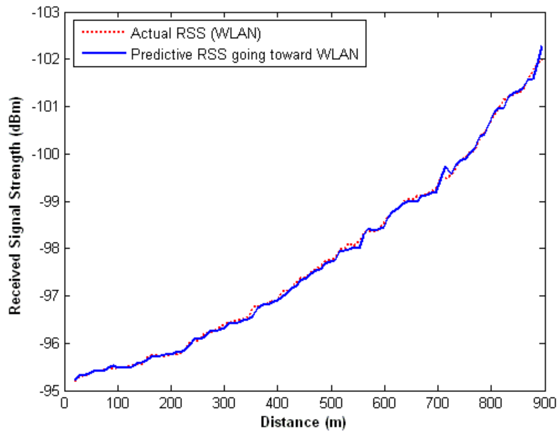


Figure 10. Predictive RSS received from WLAN access point when a mobile node is moving toward WLAN

Table 2. Networork Parameters

Network Parameters	WLAN		Mobile WiMAX		UMTS	
	Data (per kbyte)	**Voice** (per minute)	**Data** (per kbyte)	**Voice** (per minute)	**Data** (per kbyte)	**Voice** (per minute)
Cost : min / max	0.1 / 0.4	0.8 / 3.0	0.3 / 0.5	1.0 / 4.0	0.7 / 2.5	0.5 / 2.0
Bandwidth (Mbps) : min / max	1 / 4	-	2 / 6	-	-	0.1 / 0.384
Cell radius (m)	100		1500		3000	
Transmission power (w)	0.1		0.5		1.0	
User capacity	20		100		1000	
Bandwidth (Mbps)	11		15		0.384	
Mobile's velocity (m/s)	< 3		< 33		< 80	
Service application (Mbps)	< 5		< 10		< 0.384	
User preference:	5 to 10				0 to 5	
RSS of downward (dBm): min / max / th	-107 / -102 / -112				- / - / -115	
RSS of upward (dBm): min / max / th	-102 / -99 / -96					

Table 3. Simulation Parameters

Simulation Parameters	Values
Initial random number of mobile nodes	10 – 100 nodes
Average call holding time (Exponential distribution)	180 s
Default value of dwell time $(\hat{t}_d)$	2 s
Exponential smoothing factor (α)	0.5
$ubound(t_d)$ for different velocity intervals : $0 < v \le 10 / 10 < v \le 20 / 20 < v \le 30$ (m/s)	10 / 5 / 3.5 s
The number of past samples (T)	11

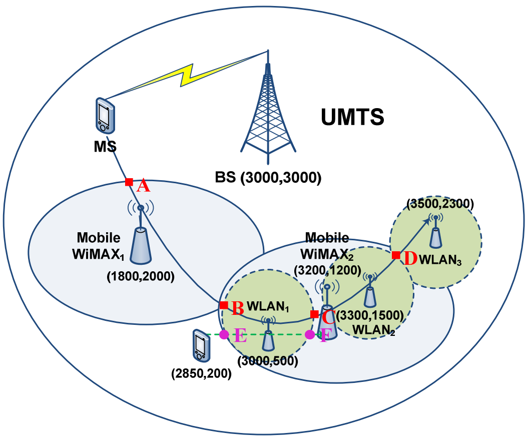


Figure 11. Heterogeneous wireless networks integrating with WLAN, Mobile WiMAX and UMTS

7.2 Network Selection Performance

Figure 11 shows the heterogeneous wireless networks consist of UMTS, WLAN and WiMAX overlaid. The mobility of a mobile node is fixed according to the path from point A to point D as shown in Fig. 11. The user speed is constant at 5 m/s. The service is running at 64 kbps. The calculated merit functions (F_n) where the handoffs occur at the points A, B, C and D are shown in Table 4. The selected network at each point has the largest F_n. The vertical handoff occurred at location A is from UMTS to $WiMAX_1$. Thus, the F_n value of $WiMAX_1$ is more than that of UMTS. At the location B, there are three networks available but $WLAN_1$ is the optimal target network. $WLAN_1$ has the largest F_n value due to the policy to prolong the time users stay in WLAN. Between UMTS and $WiMAX_2$, $WiMAX_2$ is the selected target network when the mobile node is moving out $WLAN_1$ at location C. Consider the last location D where the mobile node is going from $WLAN_2$ to $WLAN_3$. Accordingly, $WLAN_3$ is the correct target network and has the highest F_n. The results indicate that the proposed PRSS+Merit approach can trigger handoff if needed and choose the optimum target network as well.

Table 4. Merit Functions of Candidate Networks

Location	Candidate Networks (n)	F_n
A	UMTS	0.6551
	Mobile $WiMAX_1$	**0.7755**
B	UMTS	0.3987
	Mobile $WiMAX_1$	0.4188
	Mobile $WiMAX_2$	0.6945
	$WLAN_1$	**0.7309**
C	UMTS	0.3876
	$WLAN_1$	0.4518
	Mobile $WiMAX_2$	**0.6149**
D	UMTS	0.3856
	$WLAN_2$	0.5638
	$WLAN_3$	**0.5957**
	Mobile $WiMAX_2$	0.5373

Table 5. Distance when Handoff Occurred

Distance (m)	PRSS+Merit	Mamdani	Max(PRSS+HT)
UMTS to WLAN/WiMAX	37	52	75
WLAN/WiMAX to WLAN/WiMAX	230	255	270

7.3 Handoff Decision Performance

In this subsection, we present the simulation results to show the performance of the proposed PRSS+Merit approach by comparing to other two methods, Mamdani fuzzy logic based vertical handoff algorithm (Mamdani) as described in section 6 and the traditional method using the maximum of the PRSS and hysteresis threshold UMTS-to-WLAN/WiMAX handoff, the distances are 37, 52, 75 meters by using PRSS+Merit, Mamdani and Max(PRSS+HT) methods, respectively. The PRSS+Merit algorithm decides to handoff before other methods. Moreover, the PRSS+Merit algorithm early handoffed the mobile node before the location E where is the boundary of entering the $WLAN_1$. The distance between the location E and the initial point is 50 meters. In the second handoff from WLAN/WiMAX-to-another WLAN/WiMAX network, the results can be analyzed similar to the first handoff. By using the PRSS+Merit algorithm, the mobile node is handoffed before the location F where is 250 meters far from the initial point. Therefore, the PRSS of the target networks and the current RSS of the serving network is beneficial to the mobile node performing handoff early.

To illustrate the performance of the proposed PRSS+Merit algorithm, number of handoffs, handoff call dropping probability (P_h), Grade of Services (GoS) and utilization of WLAN/WiMAX networks are considered. The GoS function can be defined as [10]

$$GoS = P_n + kP_h \tag{23}$$

where P_n is a new call blocking probability and k is the penalty. The impact of the handoff call dropping is over the new call blocking since dropping connections results in unsatisfactory more than blocking new connections. The range of k is recommended from 5 to 20 which we use $k = 10$ in the simulation.

First, we evaluate the performance under different velocities ranging from 5-30 m/s. The average arrival rate of new calls is fixed at 10 calls/sec for each velocity. The user movement is modeled as the random waypoint mobility [19] for each velocity. Figure 12 illustrates the number of handoffs under different mobility. The proposed PRSS+Merit approach results in the fewest numbers of vertical handoffs in comparison to the Mamdani and Max(PRSS+HT) approaches. Meanwhile, the numbers of vertical handoffs of all approach increase for high speed. The rates of increasing of the PRSS+Merit and Mamdani are more gently than (Max(PRSS+HT)) [1, 16]. The hysteresis margin (H) between WLAN/WiMAX and UMTS is 10 dBm and threshold (T) in UMTS is -107 dBm and threshold (T) in WLAN/WiMAX is -102 dBm.

To show the benefit of using the PRSS, the distances where handoffs have occurred from the initial point are listed in Table 5. The initial point is started at (2850, 200) as marked in Fig. 8. In case of that of the Max(PRSS+HT). Accordingly, the probabilities of dropping handoff calls is the fewest by using the proposed PRSS+Merit approach as shown in Fig. 13. As a result, it yields the low GoS of the PRSS+Merit approach as demonstrated in Fig. 14. Additionally, the average utilization defined as the ratio between a period of staying at WLAN/WiMAX to the whole call holding time is investigated. In Fig. 15, we can observe that the PRSS+Merit approach yields the highest average network utilization per call. The impact of velocity to the proposed PRSS+Merit approach is less than other two approaches.

The performance under different averages of arrival rates ranging from 10 to 60 calls/sec are demonstrated in Figs. 16-19. We use the random waypoint mobility [19] to model the user movement with speeds uniformly distributed between 1 to 30 m/s. In Fig. 16, the PRSS+Merit approach yields the fewest the number of vertical handoffs under various arrival rates. The more new calls arrive, the more number of handoffs is. The handoff call dropping probability of all approach increase as the arrival rate increases but the proposed PRSS+Merit approach gives the fewest probabilities as seen in Fig. 17. The GoS of the different approaches are plotted in Fig. 18 in which the Mamdani and the Max(PRSS+HT) have high GoS, but the PRSS+Merit handoff algorithm yields low GoS. In Fig. 19, the average utilization per call in WLAN/WiMAX network of all approach gently increases as the arrival rates increase which the PRSS+Merit generates the highest utilization.

In summary, the proposed PRSS+Merit approach outperforms other two approaches. It absolutely outperforms the Max(PRSS+HT) approach since a mobile node only adopts PRSS as the handoff criteria in the PRSS+HT approach and select the strongest PRSS network as the target network. It is competitive to the Mamdani approach but the tradeoff among handoff metrics makes the Mamdani approach performs worse.

8 Conclusion

We proposed the vertical handoff decision algorithm enabled by the policies of the handoff metrics. The handoff policies are different when a mobile node stays in UMTS and WLAN/WiMAX networks. To predict a mobile node is moving away from the monitored wireless networks, the PRSS is obtained by the back propagation neural network. Dwell time depending on the mobile node movement is used to check the continuity of the RSS conditions to be true long enough. After handoff is triggered, the network is selected by the largest merit value. The weights in the merit function are dynamic to the changes of the metrics values. The proposed policy-enabled vertical handoff and network selection outperforms other two approaches in reducing the number of vertical handoffs, probabilities of call dropping, GoS and increasing the utilization of WLAN networks. In the future work, handoff delay and throughput that are crucial to real time services will be analyzed.

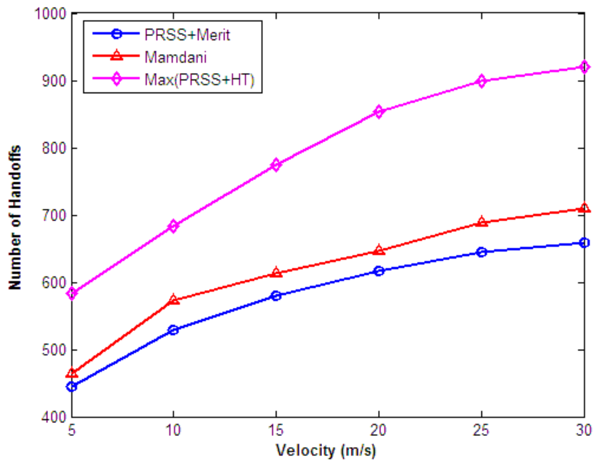


Figure 12. Number of handoffs versus velocity

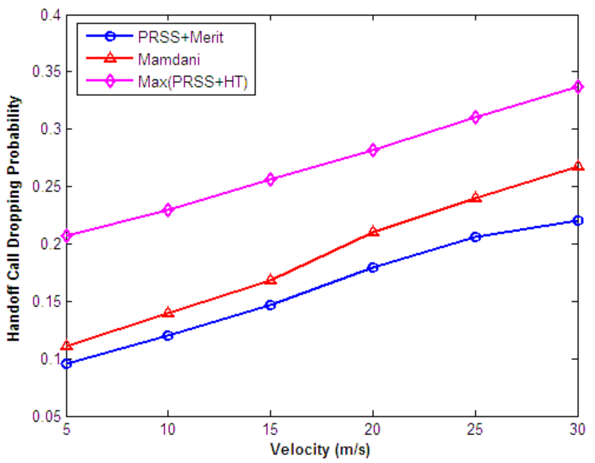


Figure 13. Handoff call dropping probability versus velocity

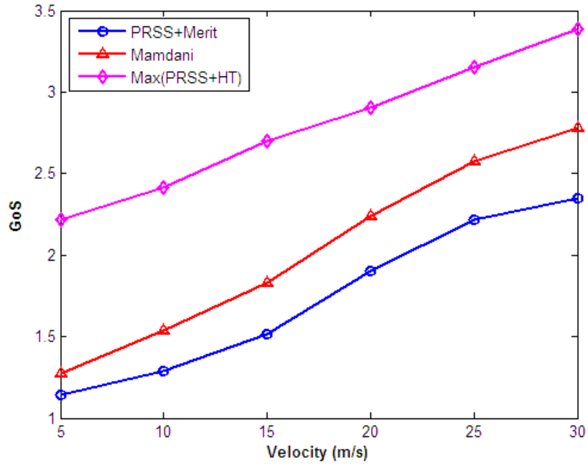


Figure 14. Grade of service versus velocity

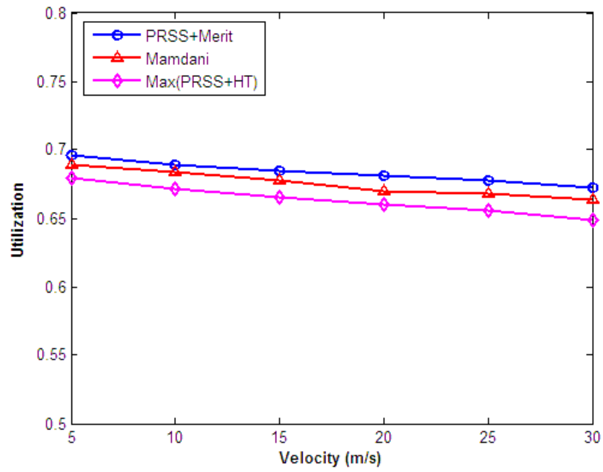


Figure 15. Utilization for non-real time services versus velocity

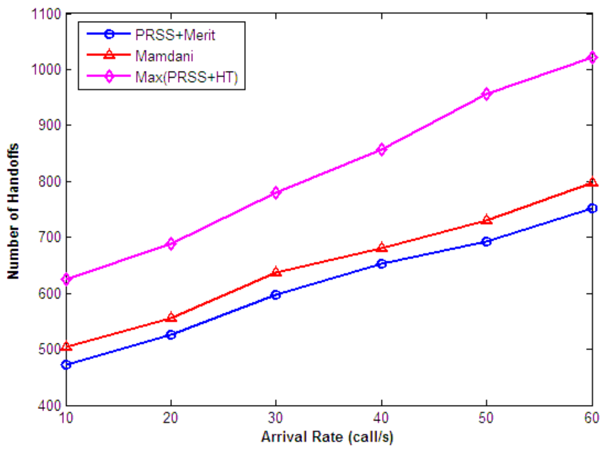


Figure 16. Number of handoffs versus arrival rate

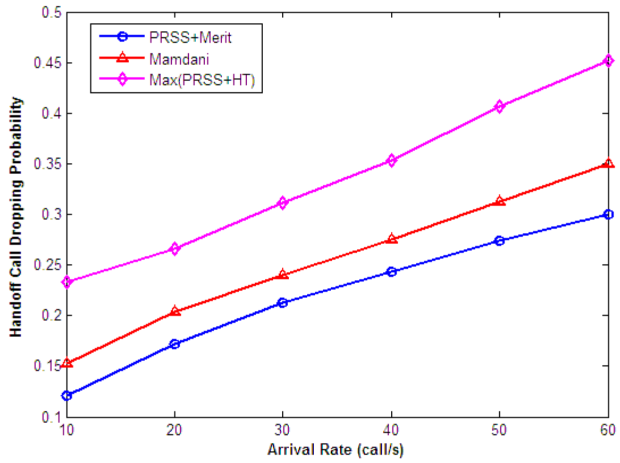


Figure 17. Handoff call dropping probability versus arrival rate

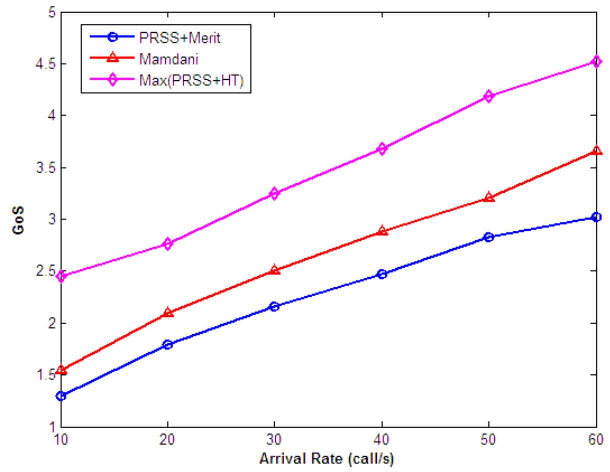


Figure 18. Grade of service versus arrival rate

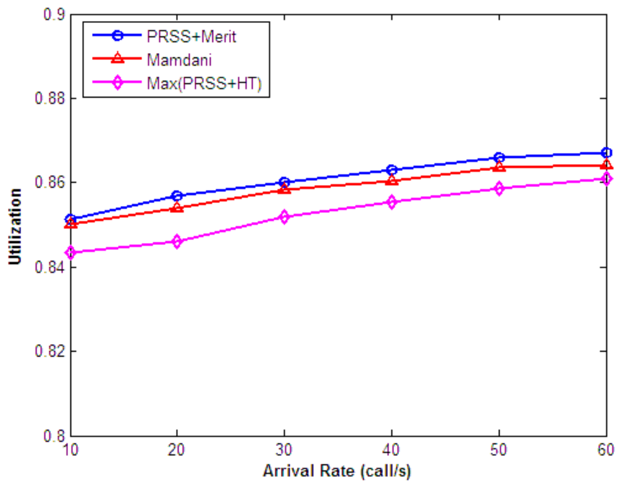


Figure 19. Utilization for non-real time services versus arrival rate

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